TECHNICAL NOTES

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PLATE METHOD OF GROUND REPRESENTATION FOR WIND-TUNNEL DETERMINATION OF ELEVATOR EFFECTIVENESS IN LANDING

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SUMMARY

An investigation was conducted in the NACA 7- by 10-foot wind tunnel to determine the validity of the stationary-plate method of ground representation for tests of ground effect on the pitching moment of complete airplane models. A 1/5-scale model of a low-wing, pursuit-type airplane with a windmilling propeller and split flaps deflected 45° was mounted in the tunnel over a plate, and the elevator deflection required for trim at the landing attitude was measured. This deflection was compared with the results of flight tests on the full-scale airplane. Sufficient data were obtained to permit the determination of the average downwash angles in the region of the tail with the ground plate present and removed.

For the type of model tested, the plate method of ground representation gave results that were in satisfactory agreement with flight-test data, the values of elevator deflection for trim in the three-point attitude being -20° in the wind tunnel and from -21° to $-22\frac{1}{2}^\circ$ in actual landings. The maximum average downwash angle at the tail when the model was near the ground plate was about $6\frac{1}{2}^\circ$; with the plate removed, the maximum angle was about 15°. The tests indicated that the maximum lift coefficient of a trimmed model would be decreased by the proximity of the ground plate.

INTRODUCTION

When an airplane approaches the ground it undergoes a marked increase in static longitudinal stability. This

increase in stability results, in a large measure, from the effect of the ground on the downwash angle at the tail. Not only is the downwash angle decreased but the rate of change of downwash angle at the tail with wing lift coefficient is smaller near the ground than at great heights from the ground. Thus, at a given airplane attitude, the tail is operating at a higher positive (or lower negative) angle of attack near the ground than at a distance from the ground, and this difference in tail angle of attack increases as the wing angle of attack increases. The rate of change of tail lift with wing angle of attack and the pitching moment caused by tail lift are therefore increased by the presence of the ground.

Another factor contributing to the increase in stability is the increase in the effective aspect ratio of the tail caused by the proximity of the ground. This factor, however, is probably a second-order effect.

In view of the increase in stability caused by the ground, a much larger elevator deflection is generally required to trim the airplane at maximum lift, particularly with flaps, near the ground than is required to trim the airplane in the same attitude at a distance from the ground. It is quite possible that the elevator, although satisfactory for other flight conditions, may not be powerful enough to trim the airplane in landing. Even when the elevator is powerful enough to trim the airplane, the deflection required may be of such magnitude that the stick force will be prohibitive. The landing condition may well be the most severe criterion in the design of the tail.

A means of determining the elevator effectiveness, when landing, from wind-tunnel tests of a model is therefore desirable. In tests of this type the ground may be simulated by an image model, by an endless belt moving with the velocity of the air stream, by a stationary plate, or by a combination of an image model and a plate. Much has been written concerning the relative merits of each method. (See references 1 and 2.) Obviously, the plate method is by far the simplest. The validity of the results obtained with this method of ground representation, is, however, open to question because of the existence of a boundary layer over the plate in the wind tunnel that is not present over the ground. Despite the doubt as to the adequacy of the plate method, it has been used in numerous investigations. (See references 3, 4, and 5.)

Although the results of these investigations (references 3, 4, and 5) are essentially in agreement as regards the effect of the ground on pitching moment, they present no direct evidence as to the applicability of the tunnel data to the full-scale airplane. In the present investigation a model was tested over a plate in the tunnel and the tunnel data were compared with flight data for the full-scale airplane. The results of the tests and the comparison are presented herein.

MODEL AND APPARATUS

The model used in the wind-tunnel tests was a 1/5-scale model of the Curtiss P-36A airplane, a low-wing, single-engine type. A sketch of the model with its pertinent dimensions is given in figure 1. A complete description of the full-scale airplane may be found in reference 6.

The tests were made in the NACA 7- by 10-foot wind tunnel described in references 7 and 8.

The ground was simulated by a flat wooden plate extending completely across the tunnel and several feet ahead of and behind the model. Details of plate construction and method of mounting are given in reference 9. The plate was set parallel to the longitudinal axis of the tunnel and its height was so adjusted that it was almost tangent to the front wheels of the landing gear with the model at zero angle of attack; the wheels never made contact with the plate. At the angle of attack for maximum lift coefficient (12°) the landing gear was about $1\frac{1}{2}$ inches above the plate. Figure 2 shows the model and the ground plate mounted in the tunnel.

TESTS

The wind-tunnel tests were made at a dynamic pressure of 16.37 pounds per square foot, which corresponds to a velocity of about 80 miles per hour under standard conditions and to a test Reynolds number of about 1,000,000 based on the mean aerodynamic chord of the model, 16.32 inches. The effective Reynolds number was about 1,600,000 based on a turbulence factor for the tunnel of 1.6.

All of the tests, except the one of the complete model without the ground plate, were made with the propeller windmilling at a blade angle of 15°. With the ground plate in place, the landing gear extended, the flaps deflected to 45°, and the stabilizer set at $2\frac{1}{2}^\circ$, tests were made with the elevator deflected 0°, -10°, -15°, -20°, and -25°. With each elevator deflection lift, drag, and pitching moment were measured through an angle-of-attack range from -4° to the stall in 2° increments. Two tests were made with the tail removed, one with the ground plate in place and one without the plate. For these tests, the flaps were deflected 45° and the angle-of-attack range was from -6° to the stall.

RESULTS

The results of the tests are given in the form of NACA standard coefficients of forces and moments with respect to the wind axes, which intersect at the center of gravity located as shown in figure 1 (26.7 percent of the mean aerodynamic chord). No corrections have been applied for tares caused by the model-support strut. Tests with the ground plate were not corrected for tunnel-wall effect. References 9 and 10 indicate that the tunnel-wall correction is negligible for the ground-plate test installation.

The coefficients used are:

C_L lift coefficient (L/qS)

C_D drag coefficient (D/qS)

C_m pitching-moment coefficient about center of gravity (M/qSc)

C_{m_t} pitching-moment coefficient about center of gravity due to tail (M_t/qSc)

where

L lift

D drag

M pitching moment

M_t pitching moment due to tail

q dynamic pressure (16.37 lb/sq ft)

S wing area (9.44 sq ft)

c mean aerodynamic chord (1.36 ft)

The following angles are given in degree measure:

α angle of attack of fuselage center line (wing is set at 1° with respect to fuselage center line)

α_t angle of attack of tail

i_t angle of incidence of tail with respect to fuselage center line

ϵ average downwash angle at tail (positive when it tends to decrease angle of attack of tail)

δ_e elevator deflection measured from chord line of tail (positive when trailing edge of elevator moves down)

δ_f flap deflection

The flight-test results used for comparison were taken from unpublished data. In these tests the elevator deflection was measured at the moment of contact with the ground. The amount of deflection required for the various landings is given in the following table:

Pilot's description of landing	δ_e (deg)
Three-point, hold-off, slight bounce, steady	$-22\frac{1}{2}$
Three-point, steady, short burst of power	-21
Three-point, floater, bounced	-21

The values of elevator deflection given in the table have not been corrected for cable stretch; but the control

forces for this airplane when landing were comparatively light, and the correction would reduce the indicated up-elevator deflection by about 1° or 2°.

DISCUSSION

Elevator deflection for landing.- The effect of elevator deflection on the aerodynamic characteristics of the model near the ground is shown in figure 3. From the data of this figure, the elevator deflection required to trim the model at any lift coefficient and angle of attack has been determined. These deflections are shown in figure 4. The portions of the curves shown by the broken lines in figure 4 were obtained by extrapolation of the pitching-moment curves of figure 3. The data presented in figure 4 show that the elevator deflection required to trim the model at the maximum lift coefficient is about -18°. The lift coefficient at which the flight-test landings were made is not known. The three-point landings, however, required an elevator deflection from -21° to -22½°. When the airplane is in the three-point attitude, the angle of attack is 14.3°. For trim at this angle of attack, the model would require an elevator deflection of -20°. The extrapolation to an angle of attack of 14.3° assumes that, at the same Reynolds number and angle of attack, the model will have the same lift coefficient as the airplane. This assumption is not necessarily valid. The lift coefficient of the model may be affected by such factors as turbulence and the boundary layer over the ground plate. In view of these considerations and the fact that the elevator deflections in actual landings are a function of the landing technique employed, agreement between the tunnel and flight data obtained in the present case is considered satisfactory.

Effect of ground on pitching-moment coefficient.- The effect of the ground plate on the pitching-moment coefficient of the model with and without the tail is shown in figure 5(a). The pitching-moment curve for the model with the tail and with the ground plate removed was estimated because the test for this condition had been made without the propeller. The curve was obtained by decreasing the slope for the propeller-removed condition about 19 percent and keeping the value of C_m at zero lift the same. This procedure is based on unpublished results of tests of a model similar to the present one.

For the model with the tail, the presence of the ground increases the slope of the pitching-moment curve from about -0.0065 per degree to -0.0140. With the tail removed, the effect of the ground is to increase the slope of the pitching-moment curve in a positive direction.

The pitching-moment coefficients contributed by the tail with and without the ground were computed from the data of figure 5(a) and the following equation:

$$C_{m_t} = C_{m(\text{tail on})} - C_{m(\text{tail off})} \qquad (1)$$

These data are shown in figure 5(b). The marked increase in slope caused by the ground proximity is again evident.

<u>Angles at the tail</u>.- From previous tests of the model the change in pitching-moment coefficient per degree change in tail incidence, dC_m/di_t, was found to be -0.0227 throughtout the flight range. This value makes possible the computation of the average angle of attack of the tail α_t by use of the following equation:

$$\alpha_t = C_{m_t} \times \frac{1}{\dfrac{dC_m}{di_t}} = -\frac{C_{m_t}}{0.0227} \qquad (2)$$

The average angles of attack of the tail for all values of model angle of attack were thus computed and are shown in figure 6(a). The same value of dC_m/di_t was used for computing α_t both with and without the ground. This procedure is probably in error because the lift-curve slope of the tail is increased by the presence of the ground. The value of dC_m/di_t should not only be larger with the ground plate in place but should also increase with model angle of attack, because the distance of the tail above the ground decreases as the model angle of attack increases. If dC_m/di_t were corrected for this effect, the values of α_t near the ground would be smaller than those shown in figure 6(a). The magnitude of this effect, however, is probably small. (See table 4 of reference 3.)

The average downwash angle at the tail was computed from the angle of attack of the model, the angle of incidence of the tail, and the angle of attack of the model tail by the formula:

$$\epsilon = \alpha + i_t - \alpha_t \qquad (3)$$

These downwash angles are shown in figure 6(b). For the case with the ground plate removed, the downwash angle increases rapidly with the angle of attack of the model. Near maximum lift, the value is about 15°. In the presence of the ground, the downwash angle slowly increases at low angles of attack. At higher angles of attack, the downwash angle is almost constant at a value of about $6\frac{1}{2}°$. If dC_m/di_t had been corrected for the effect of the ground, the downwash angles in the presence of the ground would be somewhat larger than those shown on the figure.

Effect of ground on maximum lift.- The effect of the ground on the maximum lift coefficient of the model without the tail is shown in figure 7(a). In general, these data are in agreement with the results of reference 9, which indicated that the proximity of the ground decreased the maximum lift coefficient. In the present case, however, the reduction in maximum lift coefficient was about $4\frac{1}{2}$ percent; whereas reference 9 indicates that the decrease should be of the order of 12 percent. This disparity probably results from the fact that the flap span of the present model is about 55 percent of the wing span. The data of reference 9 were obtained for full-span flaps.

The effect of the ground on the maximum lift coefficient of the complete airplane is of more practical interest. Figure 7(b) indicates that, for equal elevator deflections, the maximum lift coefficient is increased by the presence of the ground. (In fig. 7(b) the lift curve for the model with no ground was obtained from tests made without the propeller, but unpublished results of previous investigations have shown that a windmilling propeller has a negligible effect on the maximum lift coefficient or on the slope of the lift curve.)

Data for trim conditions are not available for the model used in the present investigation. The lift of a trimmed model may be expected to decrease near the ground because the pitching moment of the model without the tail is practically unaffected by the proximity of the ground (fig. 5(a)). Consequently, the tail lift required for trim will be about the same whether or not the ground is present. Since the lift of the model without the tail is decreased by the ground (fig. 7(a)) and the tail lift is the same with or without the ground, the lift of the

trimmed model near the ground should be reduced. The unpublished results of tests of a model similar to the present one bear out this conclusion. In these unpublished tests the maximum lift coefficient without the ground plate was 1.56 with an elevator deflection of about -13° for trim. The model near the ground was trimmed at a maximum lift coefficient of 1.51 by an elevator deflection of -30°. The decrease in lift was thus about 3 percent.

CONCLUSIONS

In the present investigation, and for the type of model tested:

1. The plate method of ground representation for the determination in the wind tunnel of elevator effectiveness when landing gave results in satisfactory agreement with flight tests.

2. The presence of the ground plate decreased the maximum average downwash angle at the tail by more than 50 percent.

3. The maximum lift coefficient of a trimmed model would be decreased by the presence of the ground plate.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., August 9, 1941.

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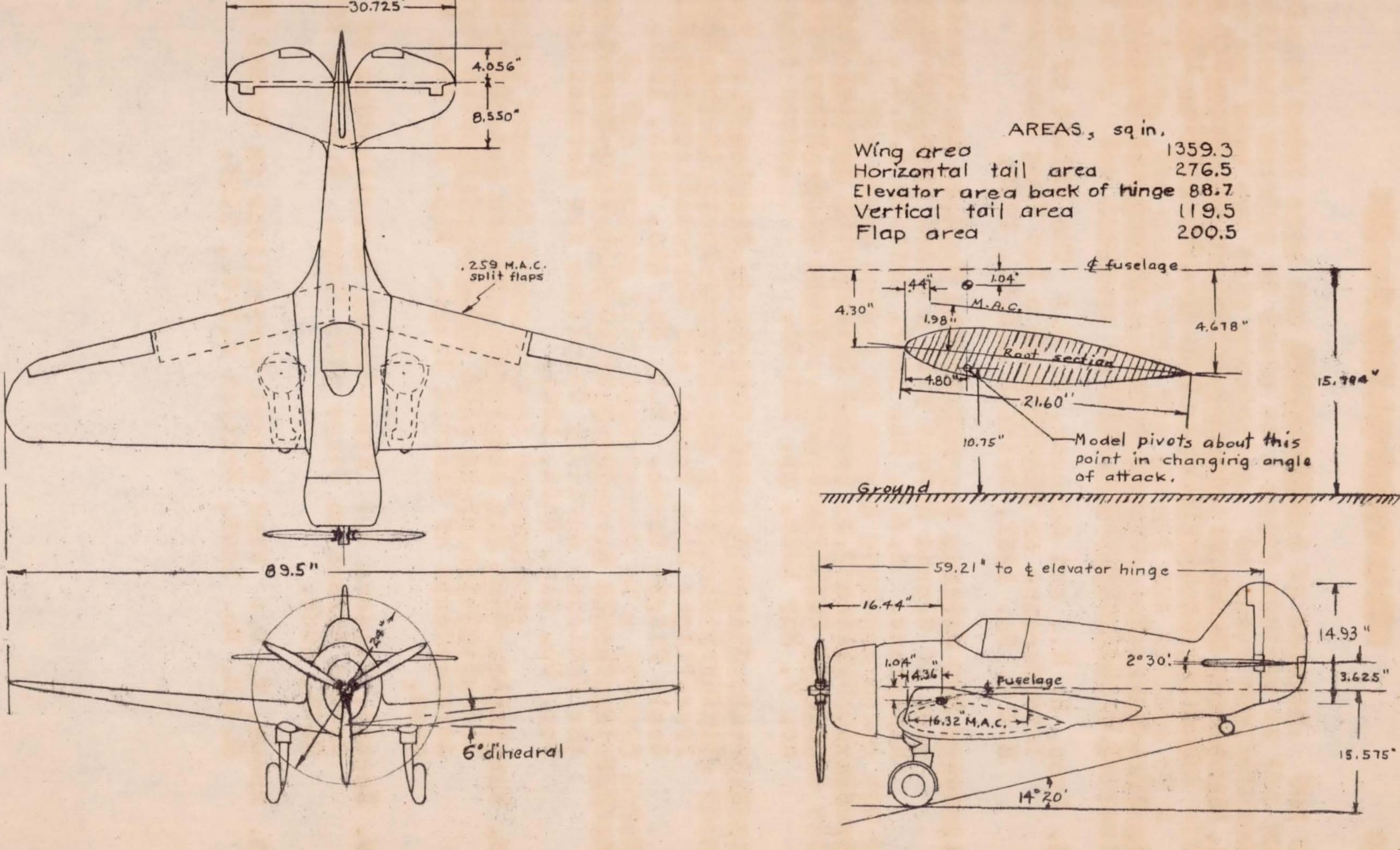


FIGURE 1.- THE $\frac{1}{5}$-SCALE MODEL OF CURTISS P-36A AIRPLANE.

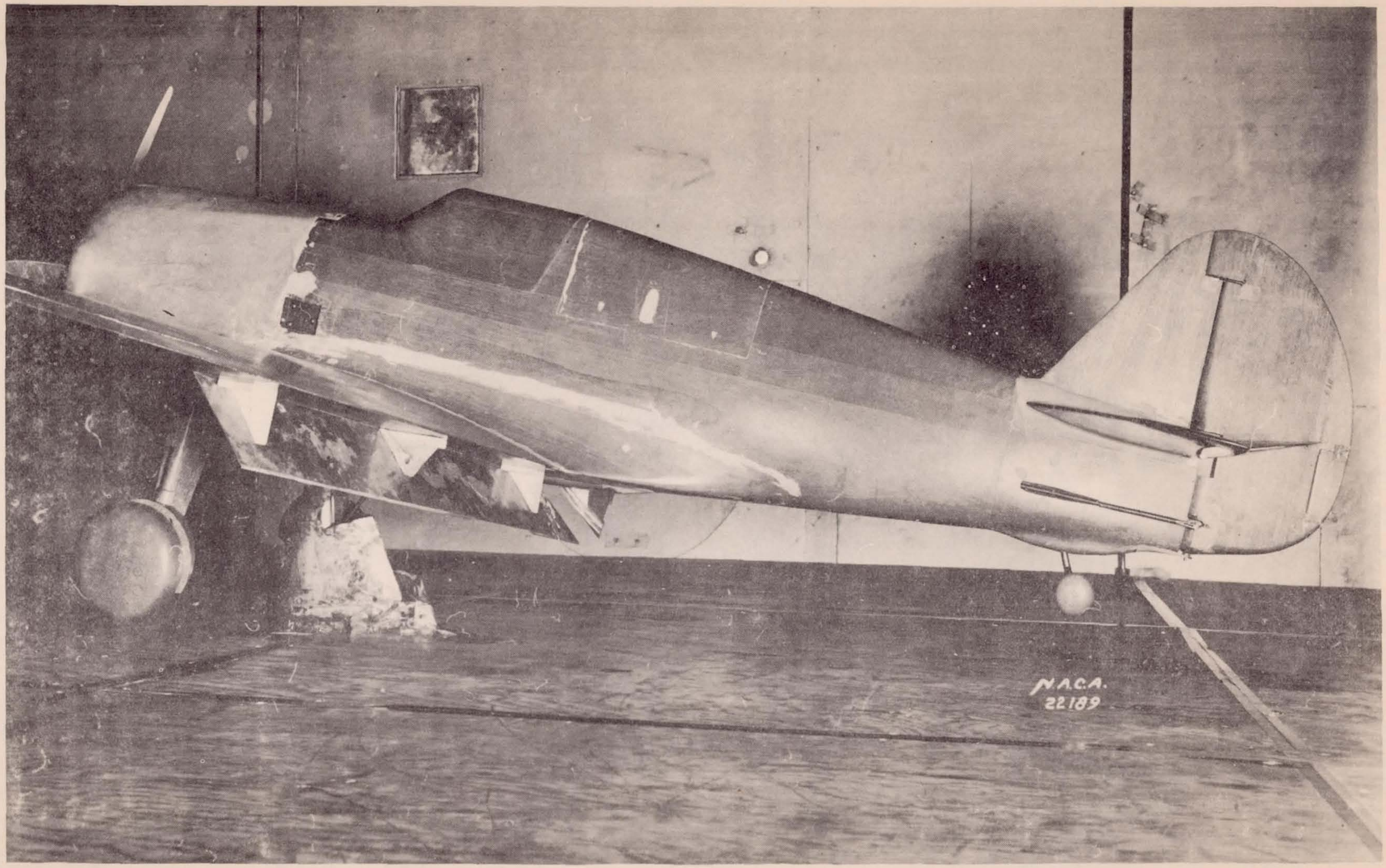


Figure 2.- Curtiss P-36A airplane model (1/5- scale) mounted on ground plate in NACA 7-by 10-foot wind tunnel.

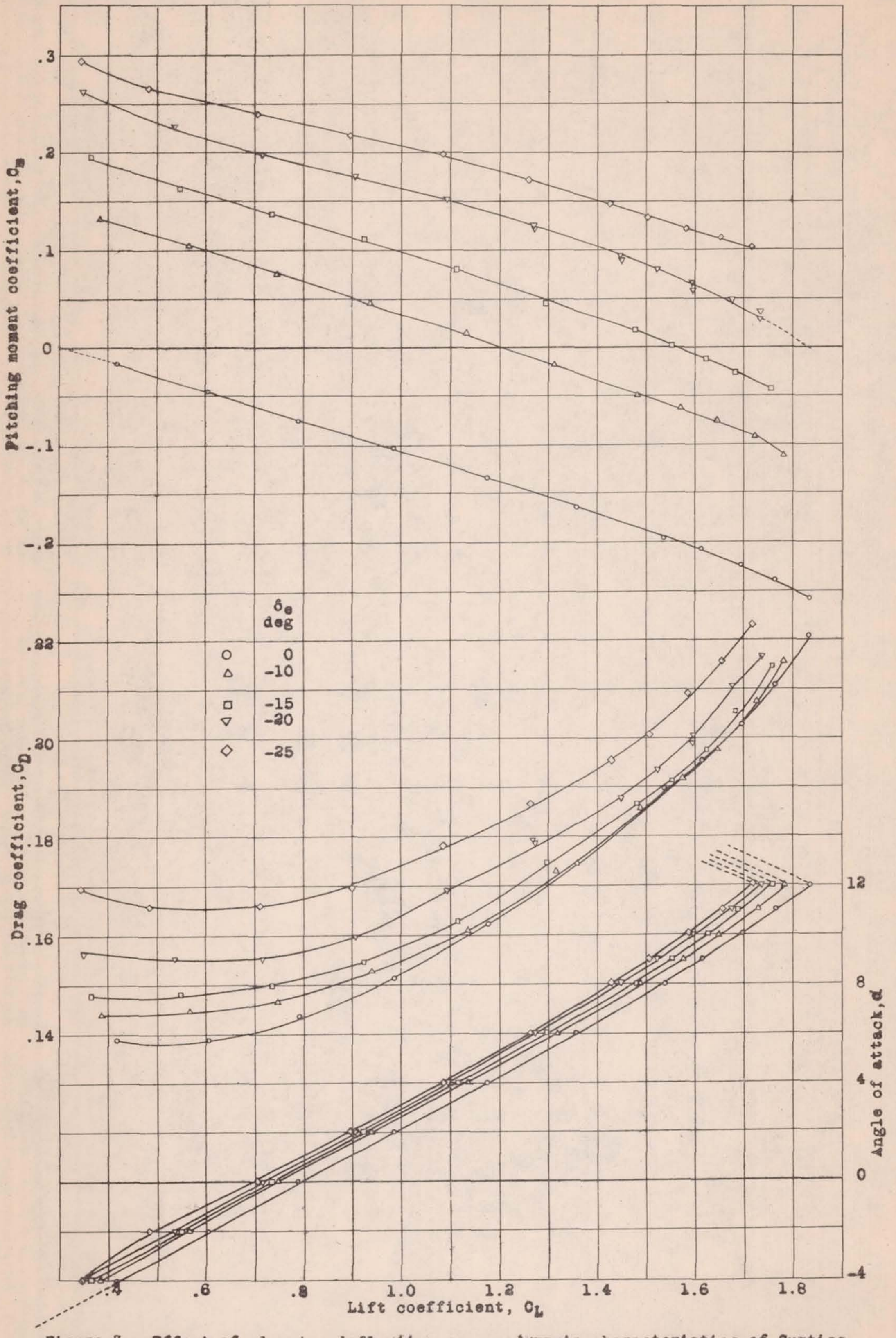


Figure 3.- Effect of elevator deflection on aerodynamic characteristics of Curtiss P-36A model near ground. Propeller windmilling; landing gear down; i_t, 2°30'; δ_f, 45°.

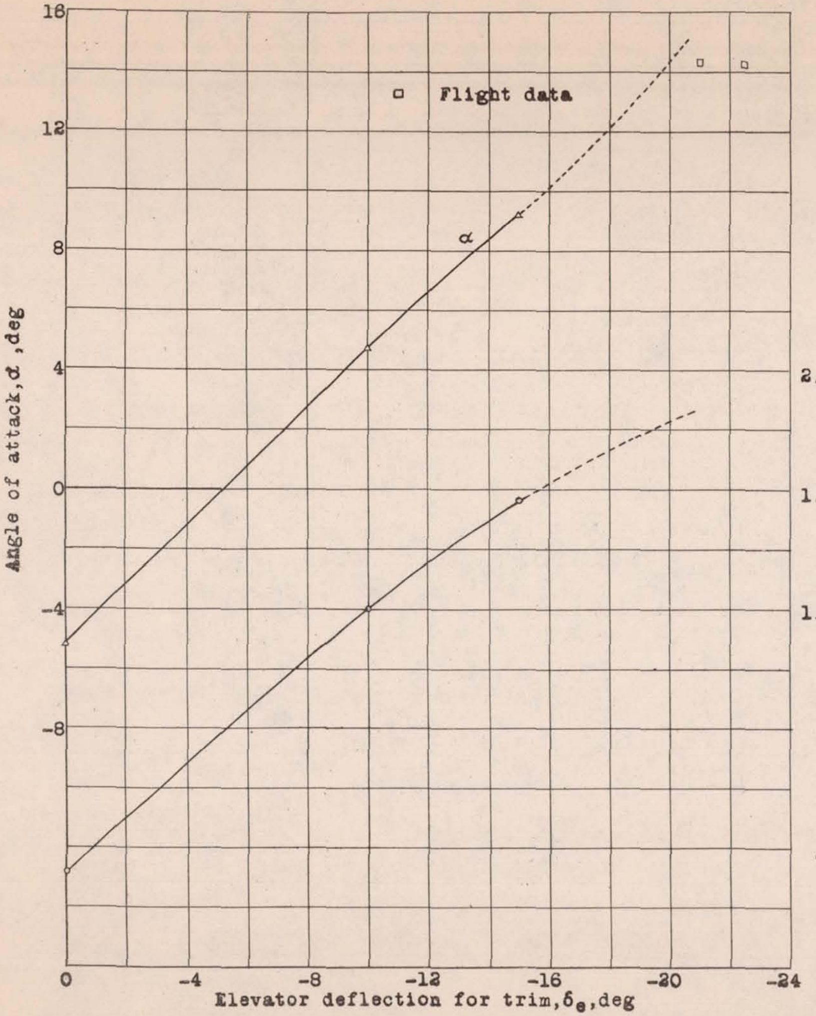
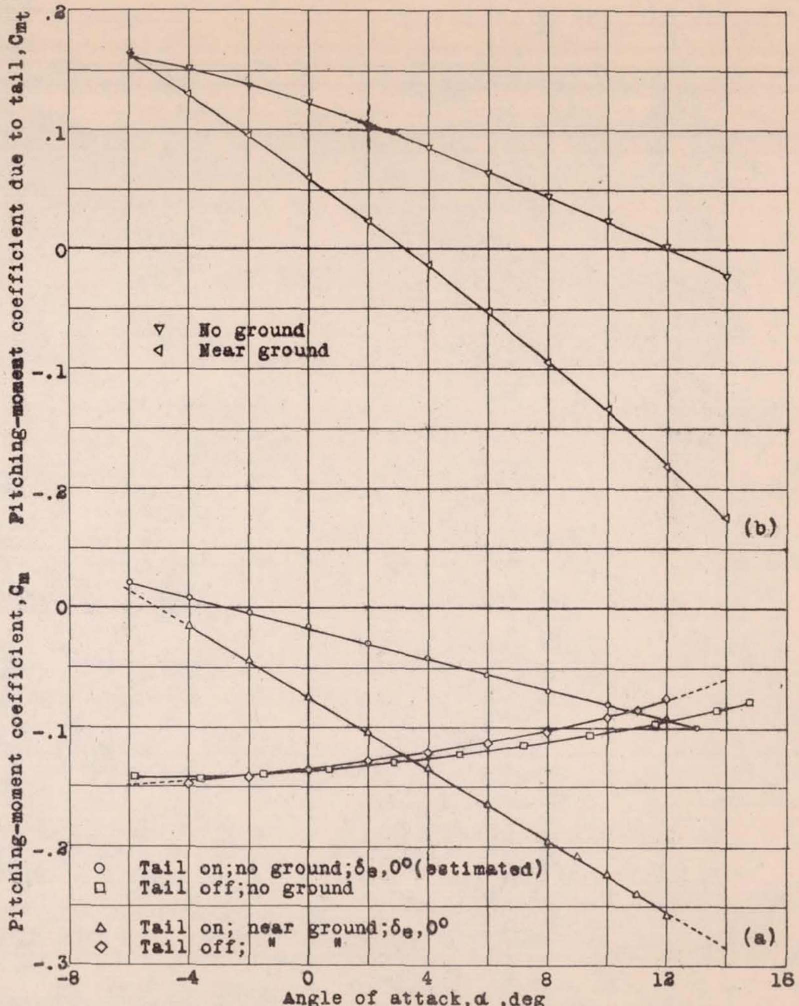


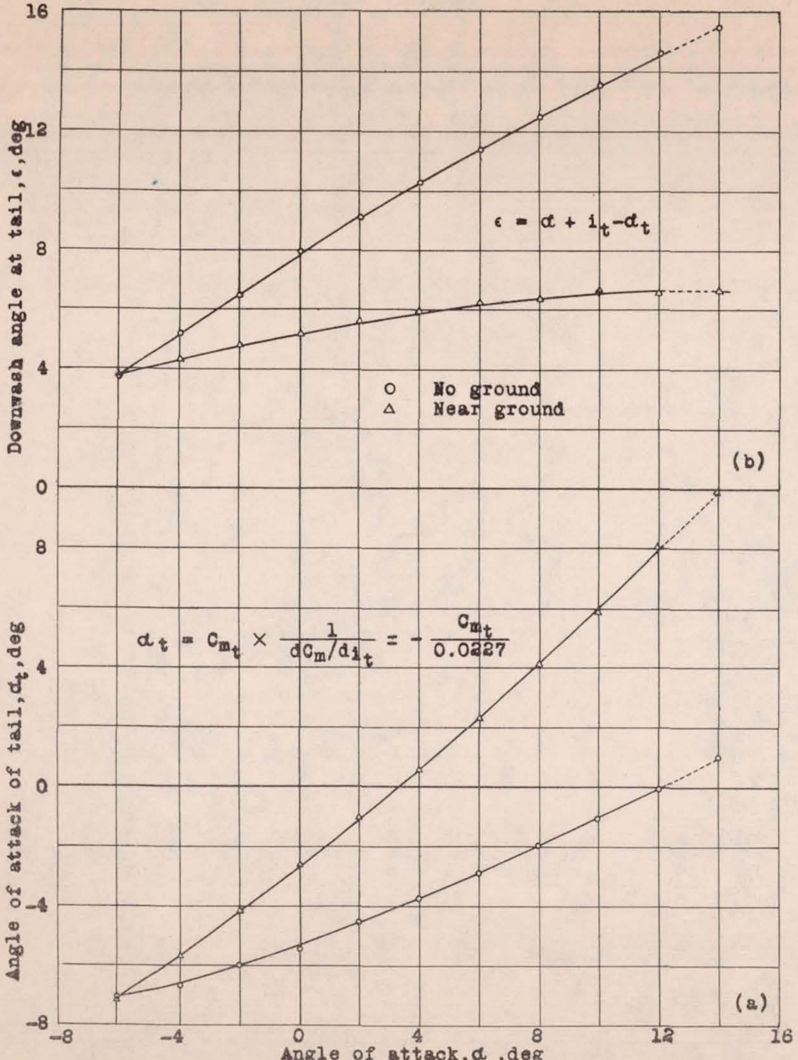
Figure 4.- Elevator deflection required to trim Curtiss P-36A model near ground at any lift coefficient or angle of attack. Propeller windmilling; landing gear down; i_t, 2°30′; δ_f, 45°.



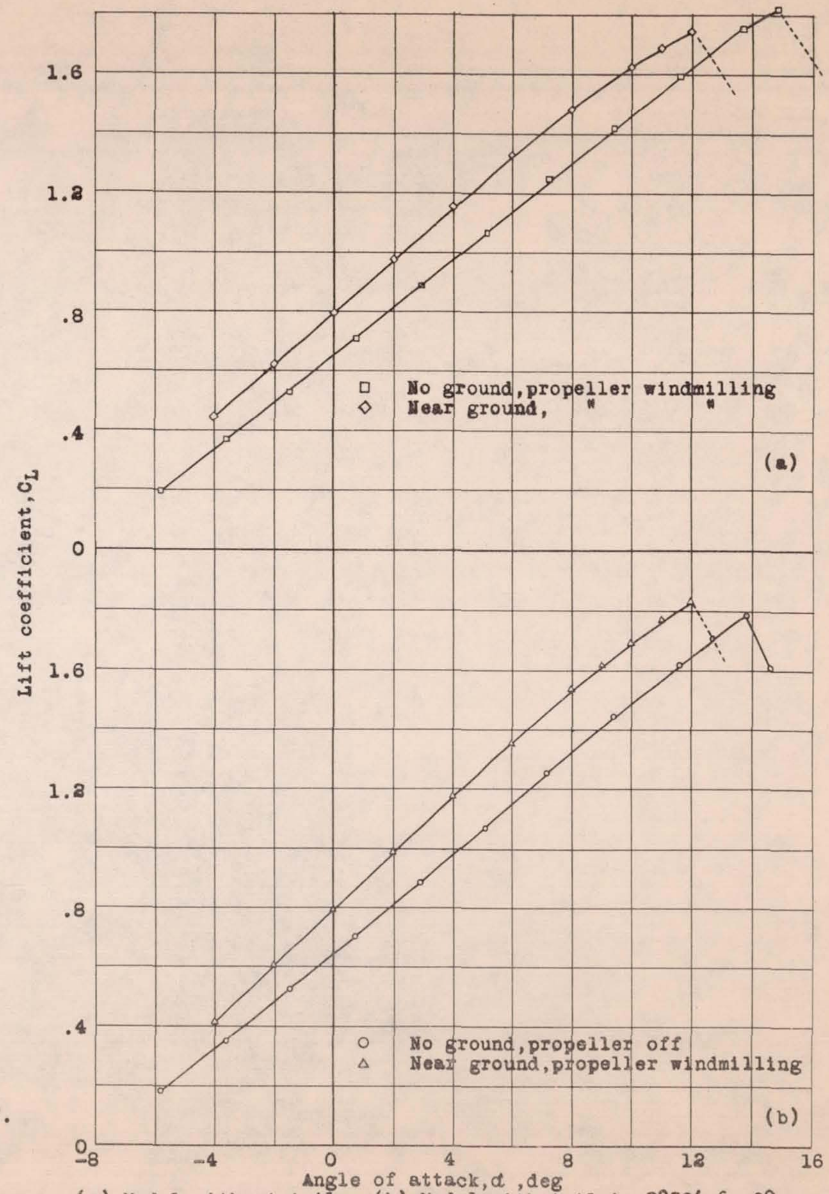
(a) Model with and without tail. (b) Tail alone.

$C_{m_t} = C_{m(\text{tail on})} - C_{m(\text{tail off})}$

Figure 5.- Effect of ground on pitching-moment coefficients of Curtiss P-36A model. Propeller windmilling; landing gear down; i_t, 2°30′; δ_f, 45°.



(a) Angle of attack of tail. (b) Downwash angle at tail.
Figure 6.- Effect of ground on angles at tail of Curtiss P-36A model. Propeller windmilling; landing gear down; i_t, 2°30′; δ_f, 45°; δ_e, 0°.



(a) Model without tail. (b) Model with tail, i_t, 2°30′; δ_e, 0°.
Figure 7.- Effect of ground on lift coefficient of Curtiss P-36A model (1/5-scale). Landing gear down; δ_f, 45°.